SEDIMENT, SEDIMENTATION, AND ENVIRONMENTS OF THE LOWER HACKENSACK RIVER AND NEWARK BAY ESTUARY COMPLEX


ABSTRACT

The Meadowlands, the lower Hackensack River, and Newark Bay in New Jersey form a connected estuarine system that is an important asset for the greater New York City metropolitan region because of its economic, environmental, and recreational value. The Corps of Engineers is deepening Newark Bay and at the same time initiating enhancements under the Hudson-Raritan Estuary Ecosystem Restoration Study. e4sciences|Earthworks LLC has produced sediment and ecological maps of Newark Bay and the lower 22 kilometers (14 miles) of the Hackensack River, which includes the Meadowlands. The accuracy is ±0.3m (±1ft).

The fundamental concept is that different sediment deposits have distinctive measurable properties and behavior. On this basis, we can map, quantify, and characterize the deposits. The maps form the basis of targeted coring and testing as opposed to more expensive random testing.

The mapping program included sub-bottom seismic profiling, orthosonography, multibeam bathymetry, magnetometry, digital photography, aerial photography, cores, sediment profile imagery, morphology, stratigraphy, sedimentation, biological data, and benthos. The geophysical methods imaged the water-bottom morphology and subsurface stratigraphy to 30.5 meters (100 feet) depth with 0.6-meter (2-foot) spatial resolution.

Keywords: Dredging, beneficial uses, slurry transport, dredged material disposal, partially oil-saturated sediment.

INTRODUCTION

The Hudson-Raritan Estuary of New York and New Jersey is one of the largest estuaries on the East Coast of the United States. It includes part of the New York City metropolitan area and includes the Port of New York and New Jersey. The estuary is an important economic, environmental, and recreational resource and asset for the region. Fresh water enters the estuary from the Hudson, Hackensack, Passaic, and Raritan Rivers. Since the 17th Century, the estuary has experienced industrialization and residential growth that have profoundly altered the estuary and surrounding land from its pre-Colonial state.

In 1999, Congress directed the U.S. Army Corps of Engineers (USACE) to conduct the Hudson-Raritan Estuary Ecosystem Restoration Study. The goal is to develop a long-term Comprehensive Restoration Plan of environmental improvements to enhance the ecological value and richness of the estuary. The Restoration Study was funded equally by the USACE and the Port Authority of New York and New Jersey (PANYNJ).

An early step to restoring and managing the estuary is to determine its current state, which included high-resolution geophysical and ecological mapping. The mapping of the study area forms a connected system encompassing the Meadowlands, the lower Hackensack River, Newark Bay, Berry’s Creek, and Berry’s Creek Canal (Figure 1).

The geophysical focus was to produce a baseline for the morphology, sediments, rocks, and properties of the waterways in the study area. The ecological objective was to establish a baseline for characterizing existing benthic populations and their health, and to assess the implications for ecosystem management. Going into these studies, a presumption held by many familiar with the study area was that the water bottom would be covered largely by industrial-age, post-colonial black silt, also known as anthropogenic sediment, harbor mud, ooze, or "black mayonnaise" (Murphy et al., 2004). The results of this study contrast with that presumption.

This paper emphasizes the high-resolution geophysical results from these shallow waters (1 to 20 m), in this active, challenging environment. We also discuss the findings of the ecological mapping and the correlation between all the techniques to assess the current state of the system.

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Figure 1. Location map of the Hudson-Raritan estuary from orthorectified aerial photograph (USGS – 1995).
STUDY AREA

The study area encompasses, from north to south (landward to seaward), the lower Hackensack River, Berry’s Creek, Berry’s Creek Canal, and Newark Bay (Figure 1). The lower Hackensack River is a 22km (14 mile) segment of the Hackensack River that runs north to south from Overpeck Creek and empties into Newark Bay. The lower river parallels the lower Hudson River Valley. The Palisades Sill separates the Hackensack River from the lower Hudson River Valley by about 5km (3 miles). The depths of the thalwegs of the river range from 3 to 21 m (10 to 70 ft) and have maintained themselves for over 100 years. The shallow flats vary from nonexistent in some bends to a broad gradation across the width of the river, particularly in the north.

Throughout the lower Hackensack River, the sediments, sedimentation rate, and sedimentary structures vary widely and locally. Diurnal tidal currents ebb and flood and control the sedimentary morphology in the estuary. The Holocene sedimentation rate is low, as sediment continually moves in the river. Exceptions are in a few areas of higher deposition that are leeward of the tidal flux. The sedimentation in the river is controlled by geometry. The floor is produced by the Triassic-Jurassic rocks and the top of the Pleistocene. The engineered shoreline confines the system laterally. These features control the accommodation space and tidal flow that in turn control sedimentation.

Berry’s Creek is a natural tributary of the tidally controlled, lower Hackensack River. Berry’s Creek drains the upper Meadowlands (Figure 1). Berry’s Creek Canal is a man-made canal constructed by dredging between 1902 and 1908. Semi-diurnal tides dominate the flow of water in Berry’s Creek and Berry’s Creek Canal. The tidal flow is strongly affected by winds. The west winds weaken the tides, and east winds amplify the tides.

Newark Bay is a complex estuary. Newark Bay is fed freshwater by the Hackensack and Passaic Rivers in the north and tidal ocean waters from Kill Van Kull and Arthur Kill in the south. Human influence on Newark Bay has been profound from shoreline development to channel dredging to ship traffic. The dynamic processes involved in Newark Bay include tidal currents, wind waves, slope failures and gravity flows, river flows and floods, boat wakes, ship-propeller scouring, and dredging. All processes have an effect on transport and deposit sediments. The stratigraphy of Newark Bay consists of rocks from the Triassic and Jurassic and sediments from the Pleistocene and Holocene epochs. The Holocene consists of black silt and gray sand and silt.

SHALLOW-MARINE HIGH-RESOLUTION GEOPHYSICS AND GEOLOGY

Making multiple measurements simultaneously lowers the uncertainty in interpretation. One can quantify the accuracy of a mapping or cross section by correlating these independent measurements. Geophysical measurements for this project included multibeam bathymetry, side-scan sonar, magnetic field surveys, and sub-bottom seismic profiling. Geological measurements included study of historical data, historical borings, grab samples, sediment profiling images (Murphy et al., 2009), push-cores, vibra-cores, and gravity cores. These measurements were used to ground truth the multibeam bathymetry, side-scan sonar, and seismic data. We focus on the results of the side-scan sonar data, sub-bottom seismic data, and geological interpretation. The multibeam bathymetry was used for referencing the data. The magnetic field surveys were used to locate and identify pipes, cables crossings and identify debris located with the side-scan sonar.

A major challenge is the acquisition of high-resolution (+/-0.15 m) shallow-marine (1 m - 15 m) data in the waters of the busy New York Harbor, with constant traffic from large ships, tugs and barges, recreational fishing boats, and others. Traffic causes wake and wave heave and bubbles; all strongly affect data quality. Other challenges are the weather and tides, which affect wave height and bathymetry, respectively. These factors also affect how data from different times of the day connect. Water depths (less than 1.5 m) made data acquisition a challenge. Entry into the tributaries was more limited than expected because of shallow water depths. Ebb flow dominates the morphology at the junctions with tributaries; therefore, the key features were measured in the river. Additionally, accurate data positioning is a challenge in areas where interference from large bridges occurs.

Orthosonographs™

We developed a processing method for side-scan data that results in a pair of complementary orthosonographs (Ward, 2004). Each pair of orthosonographs provides 100% seamless coverage of the same area of investigation but with illumination from opposite directions (i.e. illuminated from the east which emphasizes the western side of the...
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river; illuminated from the west which emphasizes the eastern side of the river). The acquisition frequency for the side-scan sonar data is 440 kHz.

Figure 2 shows an example of such orthosonographs. Top image shows an oblique aerial photograph of a segment of Berry’s Creek at the Hackensack River. Middle image is an orthosonograph ionized from the north that shows emphasis on the south portion of the creek. Bottom image shows an orthosonograph ionized from the south that shows emphasis on the north portion of the creek. The aerial photograph shows the ebb flows (A) from the creek that is also distinguishable in the orthosonograph illuminated from the north. Similarly the feature labeled (B) is also indentified in both the orthosonograph illuminated from the south and the aerial photograph. Notice that each orthosonograph gives complementary information.

Seismic sub-bottom profiling

We acquired sub-bottom profiles for the length of the lower Hackensack River, Newark Bay, Berry’s Creek, and Berry’s Creek Canal. After testing a range of sweeps, we used a chirp source with a frequency range from 1-10 kHz, which provided a compromise between signal penetration and resolution. The data processing consisted of simple dechirping, bandpass filtering, time-varying gain, and zero-offset time migration. The time-to-depth conversion was benchmarked and calibrated to the historical borings and bathymetry, using velocities obtained from measurements on the sediments and rocks in the lab and water velocity measurements in the field.

Some seismic sections have challenging imaging problems: 1) low-velocity attenuation layer due to large accumulations of black silt and 2) strong lateral velocity variations from low-velocity Holocene/Pleistocene sediment layers and high-velocity Jurassic/Triassic diabase and shale. To handle these challenges we use zero-offset wave-equation migration. The velocity model was built by combining prior geological knowledge of the area with focusing and defocusing of major diffractions.

Borings

We digitized, mapped, and rectified all of the available historical USACE, PANYNJ, New Jersey Department of Transportation (NJDOT), and New Jersey Geological Survey (NJGS) borings in the area of investigation. We used this information to grid and contour two subsurface horizons: the top-of-rock and the bottom of the Holocene horizons. These horizons are bounding surfaces for the Pleistocene glacial till and lake sediments, with Holocene sediments above and bedrock below.

Shallow core borings

We acquired one hundred and twenty (120) shallow (0.5-1 m) push cores in the Hackensack River, and over one hundred (100) gravity cores in Newark Bay. The purpose of the cores was to (a) determine the stratigraphy in the shallow sediments, (b) identify black silt deposits, and (c) calibrate and test the side-scan sonar imaging and sub-bottom seismic results. The core locations were picked on the basis of preliminary interpretation of the bathymetry, seismic data, and geomorphology. The spatial distribution was irregular. This core-location-selection strategy allowed us to characterize the various environments with fewer cores than would be required with a regularly spaced grid or random sampling.
Figure 2. From top to bottom: oblique aerial photograph of the entrance to Berry’s Creek at the Hackensack River. Orthosonograph illuminated from the north. Orthosonograph illuminated from the south with emphasis in the north portion of the creek.

Figure 3 is a photograph of gravity cores obtained in a black-silt area. Notice the extension of the black silt on top of reddish Pleistocene clay. Such cores serve to calibrate our interpretation of side-scan orthosonography and chirp seismology data. Black silt consists of approximately 50% silt particles, 25% water, and 25% hydrocarbons with trace amounts of heavy metals. Its compressional-wave properties are sensitive to temperature. These unique properties make it possible to map its distribution and thickness using orthosonography and reflection seismology.
Figure 3. Photograph of shallow sediment cores. (A) shows a thick black silt layer. (B) shows the contact between black silt sediments and Pleistocene clay.
OBSERVATIONS

The orthosonograph images are processed and calibrated to indicate rock as white and mud as black with grades of yellow and brown indicating sediment type from sand to silt as in Figure 4. We interpret the areas of low reflectivity (darker colors) to be softer and finer-grained sediments that absorb sound. The Recent black silt is nearly black in the images. The stiffer and coarser-grained sediments and rocks reflect more sound and appear as lighter colors. The areal photograph indicates the direction of water flow; this is also identifiable in the direction of sediments observed in both orthosonographs (features A and B).

Black silt in this area is highly mobile and has returned to southern Newark Bay. Figure 4 shows two orthosonographs of Newark Bay, both illuminated from the west. The difference lies in the acquisition time. Left was acquired in 2001. Right was acquired in 2005. The data acquired in 2001 was acquired when the channel was at -12.8m (-42ft) elevation. Note the areas of black silt (dark gray lines) and the ship tracks. Afterwards, the channel was deepened to -14.3m (47ft). The surface black silt in the channels was cleared by environmental dredging. The orthosonograph obtained in 2005, after dredging, shows that much black silt had returned. Most of this recent sediment came from the flats on the eastern side of Newark Bay. The 2001 acquisition data guided the dredging and cleaning. The 2005 image shows that black silt has returned as it flushes from the flats. Dark gray circles mark the extension of black silt. The figure shows the bottom has been scoured along the ship paths and turning areas. The black-silt footprint in the channels is dynamic and changing constantly with the currents and ship traffic. This interpretation from sonar imaging is consistent with core borings and sub-bottom profiling. The maximum thickness is 0.6m (2.0ft) in the channels; the maximum sedimentation rate is 0.3m/yr (1.0ft/yr).

Figure 4. Two orthosonographs for Newark Bay, both ionized from the west. Left was acquired in 2001. Right was acquired in 2005. Both images are overlayed on an orthorectified aerial photograph from USGS – 1995.
Figure 5 shows a portion of the orthosonograph from 2001 in Newark Bay draped on top of multibeam bathymetry. Also note the ship tracks all the centerline. The ships push the black silt to the side. The channel bottom shows scouring features down to the top of Pleistocene, ebb-flow tidal deltas, and flood sand waves (figure 5). Thick deposits of recent black silt accumulate along the channel toe.

Figure 5. Orthosonograph from 2001 in Newark Bay, combined with multibeam bathymetry.
Figure 6 shows a processed subbottom seismic image along Berry’s Creek Channel. This data was acquired in waterdepths of 1m – 3m (3ft – 10ft). The oblique aerial photograph shows the portion of the creek relevant to this dataset. The brown interpretation line indicates the top of rock boundary. The orange line represents the Holocene-Pleistocene boundary, the yellow double-arrow in the areal photograph delimits the area covered by the seismic line. The top-of-rock is clearly observed in most of the seismic records (brown interpretation line). In the tidal scours, the Holocene is thin (orange line), and the Pleistocene varved silts and clays may be exposed and eroded in some places. The Pleistocene sediments are relatively impermeable and contain little or no industrially related material.

Figure 6. Top: oblique aerial photograph of a portion of Berry’s Creek Channel. Bottom: Processed subbottom seismic image along Berry’s Creek Channel.
Ecological

The profile images show that there is considerable spatial variability in substrate types and habitat conditions (Figures 7D, 7F, and 7G). Both soft-bottom and hard-bottom habitat conditions were encountered, with substrate types ranging from consolidated clays to gravel. Layering of different types of sediment (e.g., sand-over-mud, gravel-over-clay, etc.) were visible in the images and attributed to frequent cycles of erosion and deposition. These cycles represent a physical disturbance factor that contributes to the overall variability in substrate types and habitat conditions.

Figure 7: Summary of primary results of e4sciences|Earthworks investigations of Hackensack River.
Both Garrett’s and Harmon Cove reaches had predominantly silt-clay (i.e., muddy) sediments. Lyndhurst, Laurel Hill, and Marion North reaches had greater variability in substrata, ranging from silt-clay to gravel. It is hypothesized that Garrett’s and Harmon Cove reaches are located in a section of the lower Hackensack River that favors the net long-term accumulation of fine-grained sediment and organic matter.

Neither the SPI nor the benthic grab sampling results indicated the presence of any sharp gradients or strong, consistent differences in benthic habitat quality among the reaches. At a few sampling locations, the sediments were extremely black and anoxic, which may be indicative of excessive organic loading and/or periodic near-bottom hypoxia. Such effects, however, appeared to be highly localized.

Overall, the study results show that there is considerable variability in substrate types and benthic habitat conditions within and among the five reaches. Furthermore, benthic infaunal communities within the lower Hackensack River are dominated by stress-tolerant taxa that are adapted to frequent physical disturbance and salinity fluctuations.

**Integrated interpretation**

The Meadowlands and lower Hackensack River are a connected estuary system. At Laurel Hill (Figure 1), the system funnels south into one drain. To the north, the river meanders. The river bottom of the Hackensack varies greatly. The depths of the thalwegs vary from 3m (10ft) in some straights to 21m (70ft) in the bends. A sandy and rocky channel with silt in the flats is observed in the south. Rock is exposed in portions of the river and southwest of Laurel Hill (Figure 1). The channel bottom shows scouring features down to the top of Pleistocene, ebb-flow tidal deltas, and flood sand waves.

At Harmon Cove at the mouth of Berry’s Creek and Berry’s Creek Canal, up to 40ft of Recent “industrial-period” sediments may have been deposited between 1940 and 2006. From analyses of bathymetric and historical data, the sedimentation rate was as high as 0.2m/yr (0.7 ft/yr). Lateral accretion on point bars may have produced up to 9m (30ft) of Recent black silt deposits above the Route 3 bridges. The bridges along the river affect sedimentation; the bridge channels scour and the abutments cause deposition.

The thickness of the industrial-age Recent Holocene sediments ranged roughly from 1.5 to 3 m (5 to 10 ft) throughout the reaches of the Hackensack River. The significant industrial-age sediments are deposited in the flats that were produced by meander bars. In the bars, the Recent sediments may reach thicknesses exceeding 1.5m (5ft) but less than 3m (10ft). Most of the push cores sample industrial-age sediments. Many penetrate to the Holocene-Pleistocene boundary.

Throughout this estuary system the sediments, sedimentation rate, and sedimentary structures vary strongly and locally. Sedimentation in Newark Bay is strongly influenced by dredging as well as the depth and change in slope of the navigation channels. Currents drive sediment transport and are controlled by bathymetry. In the shallow waters of the flats, sedimentation is low. Navigation channels are deep but flat. Deposition tends to concentrate where slopes descend at channel toes or in deep holes. Consequently, channel slopes are important geomorphic features, being conduits for sediment transport from the flats to the channels and barriers for sediment in channels to move up to the flats.

The rocks forming the basement of Newark Bay are the Triassic Passaic red shale in the west, the Jurassic Palisades Diabase Sill in the east, and the Lockatong sandstone and black shale in the middle. The strike is north 36° east. The dip is 15° to the northwest. Holocene sediments consist of marine estuarine silts and sands. The Holocene-Pleistocene horizon separates Holocene sedimentation above from Pleistocene glacial lake and till deposits below. The Holocene began 10,000 years ago. Estuarine waters flooded Newark Bay roughly 3,000-5,600 years ago (Douglas and Peltier, 2002).

Figure 8 shows subbottom seismic images (1-10 kHz) of sediments above diabase rock. The ordinate is the elevation; the negative sign indicates elevation below the mean-low-water (MLW) datum. (A) The diabase penetrates through the sediment and is exposed. (B) Stacking of sand waves moving up stream (to the left). The lower image shows the topset layering internal to each of the sand waves moving in the direction of the flood tide.
Core borings provide ground truth to the images. The rock basement is clearly observed in the seismic images (Figure 8). Its elevation is roughly -30m (-100ft) in the east dropping to -60m (-200ft) in the west. The strike and elevation of the rock controlled the natural trajectory of lower Hackensack River, and Berry’s Creek. The Creek lies in low valleys in the rock. The Canal was cut into Pleistocene sediments traveling up dip of the Passaic shale and short-circuits the natural pathway.

Figure 8. Subbottom seismic images (1-10 kHz) of sediments above diabase rock.
CONCLUSIONS

Before these studies, it was presumed that the Hackensack River bottom would be covered uniformly with highly viscous oil-rich Recent sediments. Our observations demonstrate otherwise. Black silt is concentrated locally in point bars and deltaic deposits in the north. Elsewhere, there is tremendous variety in type of sediments, bathymetry of river and channel bottoms controlling sedimentation. Bedrock forms the substrate that confines the Hackensack River and Newark Bay system. Engineered shorelines further confine the system laterally. Dredged channels influence the sedimentation patterns within the system.

This study showed that a careful and through combination of geological and geophysical measurements yields useful information for asset management, through the characterization of sediment and rock properties. It also demonstrates that accurate data acquisition and processing of geophysical data is possible in very shallow waters and active harbor environments. The study provided asset managers with measurements, maps, and cross sections of geological structure and stratigraphy, partially oil-saturated industrial sediments, bedrock elevations, and historical and modern infrastructure.

These integrated geophysical and ecological studies have shown that the Hackensack, Berry’s Creek, and Newark Bay area to be a dynamic estuary system. They provide measurements to document and understand the dynamic behavior of river systems. One should use measurements as a tool to restore and manage these systems in a more effective and efficient manner. Such measurement programs should become integral to the successful management and guardianship of the value of estuarine and riverine ecosystems.

REFERENCES


CITATION